The Effect of Polymer Emulsion Addition on the Setting Time, Crack Formation and Strength of Cementitious Patch Repair Mortars.

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Keywords: Polymer emulsion, patch repair mortar, crack formation, setting time, compressive strength.

Abstract. With millions of square meters of ageing exposed concrete surfaces throughout the world, concrete patch repair is becoming a major component of the civil construction industry. To ensure effective and efficient repairs and rehabilitation of deteriorating concrete surfaces, patch materials with excellent workability during the repair phase and durability during its design life cycle are required. The addition of polymer emulsions to cementitious repair mortars increase the setting time, crack resistance while negatively affects the strength properties of the mortar. Polymer emulsions include natural rubber, polyacrylonitrile and polivinylacetate, to name just a few [1].

This paper focus on the effect of adding different polymer emulsions at varying dosages to cementitious repair mortars to obtain a better understanding of the influences on setting times, crack formation properties and curing regime requirements for optimal strength development. Ambient temperature and relative humidity were kept constant during the testing cycles.

The results obtained indicated that the introduction of a polymer emulsion tend to reduce both the initial and final setting times of the repair mortars but that is extends the duration between initial and final set when compared to unmodified repair mortars. Compressive strength reductions were observed when adding polymer emulsions to the repair mortar but it was clear that crack formation was eliminated with the addition of the emulsions.

Introduction

Concrete is one of the oldest and most extensively used construction materials in the modern world because of its durability, versatility, economic efficiency and aesthetic appeal. Concrete is a very common construction material in South Africa because it has a low maintenance cost and is also used because of its availability [2].

Because concrete and cementitious patch repair mortars are such versatile construction materials, its compositions can be technological altered to lessen concrete and cementitious patch repair mortars' disadvantages, such as low tensile strength, low chemical resistance to corrosion, large drying shrinkage which form cracks and delayed setting [3,4]. One such technological improvement to concrete and cementitious patch repair mortars is the addition of polymers during the mixing proportioning, specifically polymer emulsions. These polymers emulsions include natural rubber, polyacrylonitrile, polyvinylacetate and vinylacetate to name just a few [1].

Much has been documented about the long term effects of cementitious patch repair mortars such as of hardened properties, strength development and cracking resistance as a result of polymer addition. Very little has been documented regarding the effect of polymer addition on the setting time. This gap in knowledge was the inspiration for this study in which an investigation was done by adding different polymeric emulsions to a Portland cement mortar at different dosages to get a better understanding of the setting times, curing regime requirements and the crack formation properties of repair mortars. This information is required to assist the repair practitioner to select the best suited polymer emulsion for optimal concrete patch repairs.

Research methodology and polymer emulsions used

This project focused on the impact of different polymeric emulsions when added to a cementitious patch repair mortar at different dosages on setting times, crack formation and curing requirements of such mortar. This was done by determining setting times, cube strengths at 7, 14 and 28 days and shrinkage and crack formation data over a 28 day period under different curing regimes while keeping the ambient conditions of temperature and relative humidity of the testing laboratory constant. Curing regimes used included air curing, submersion in a water bath, use of a curing compound and covering by plastic sheeting. Specimens used for compressive strength testing and crack formation analysis were cured under these conditions for 7, 14 and 28 days prior to testing.

By executing the above work, the following was determined:

- the setting times of a cementitious patch repair mortar when different dosages of different polymeric emulsions are added to the mortar
- the crack formation properties when different dosages of different polymeric emulsions are added to the repair mortar under different curing regimes
- the impact of various curing regimes on the performance of polymer emulsion modified repair mortars.

Three commercially available polymer emulsions from well-known international suppliers were used in this study. These included Emulsion A which was an alkali compatible acrylic emulsion. It is specified to be used to provide concrete with increased abrasion resistance, low permeability and mild acid resistance. This emulsion does not discolour mortars or concretes and forms a clear film after it has cured. Emulsion B was a synthetic polymer emulsion specified for use when good water resistance and adhesion are required in a cementitious mortar. It is said to improve chemical and abrasion resistance and adhesion strengths while decreasing the shrinkage of the cementitious mortars whilst also providing it with greater elasticity than that of an unmodified cementitious mortar. Emulsion C was a water reactive synthetic polymer emulsion, which contains silica fume. This emulsion is said to increase the workability of the mortar as well as the resistance to chemical attack while it further improves the bond strength and impermeability to water. It is also referred to as a reactive bonding agent and mortar improver.

The cement used in the mortar mix was a CEM IV/B-V 32,5R Pozzolanic cement and the mortar sand was a standard fine building sand oven dried for 24 hours at 110°C. The cement to sand ratio used was selected as 1:2. Clean potable water was used at a water-cement ratio of 0.8 because of the high water demand of the fine aggregate. Dosage rate per the polymeric emulsions were based on recommendations from the suppliers and varied from 1:4, 1:6 and 1:8 polymer to water ratios. The water-cement ratio was kept constant for the different dosages.

Setting time measurements

The setting times of the mortar samples were determined using a Vicatronic automatic Vicat recording apparatus. This device is able to determine the initial and final setting times of cement or mortar pastes [5]. Fig 1 shows the Vicat during a setting time measurement. Measuring of the setting times of the mortar pastes was done in accordance with SANS 50196-3:2006 – Methods of testing cement, Part 3: Determination of setting times and soundness which is similar to the EN 196-3 specification [6].

Figure 1: The Vicat apparatus in operation [5]

Compressive Strength Tests

Mortar cubes, 100 × 100 × 100mm, were used for compressive strength determined. These tests were carried out in accordance with the following SANS 5863:2006 Concrete tests – Compressive strength of hardened concrete [7], SANS 6255:2006 Mortar tests – Compressive strength of mortar [8] and SANS 50196-1:2006 Methods of testing cement – Part 1: Determination of strength [9]. Apart from cubes prepared for each of the different polymer emulsions at the different dosage rates, control specimens without polymer emulsion were made for each of the four curing methods. Allowing for cubes to be tested at 7, 14 and 28 days, a total of 360 mortar cubes were made and tested. These cubes were then cured under four curing conditions which included submerging in a water bath with temperature kept between 22°C to 25°C as required by SANS 5861-3, covering the cubes with a loose plastic membrane, painting the cubes with a curing compound after demoulding and finally with no curing whatsoever (air curing). The ambient temperature was kept constant at 22-25ºC for all four curing regimes. After density determination, cubes were compressed at a rate of 0.3MPa/s until failure.

Crack Formation Tests

Square 220 X 220mm plates of 15mm thick mortar from every dosage of the different polymeric emulsions plus control specimens were formed, cured and monitored for crack formation and development evaluated over a 28 day period. No release oil where used in the moulds. The four previously described different curing methods were followed.

The cracks are measured in length using a flexible cable and a ruler, and in width with a handheld calibrated microscope. These values were used to calculate the area of each crack at the specific time interval. The measuring procedure is shown in Fig. 2.

Figure 2: Measurement of crack area.

Results and Analysis of Results

Setting time measurements

Typical results of setting time tests are found in Fig. 3 and Fig. 4 below. The x-axis of the graphs represents the time in minutes and the y-axis represents the distance between the tip of the Vicat needle and the glass (base) plate. This means that for a y-value of zero, the mortar is still workable and the stiffening of the paste has not started. Where the graph begins to change, it is due to the Vicat needle not penetrating to the bottom glass plate. This is due to the onset of setting of the mortar resulting in stiffening. This point is defined as the initial set (T_o) of the mortar sample. When the graph level off at its peak, the mortar has set and no penetration of the needle is possible. This is the final set (T_{RF}) point and hardening now commence.

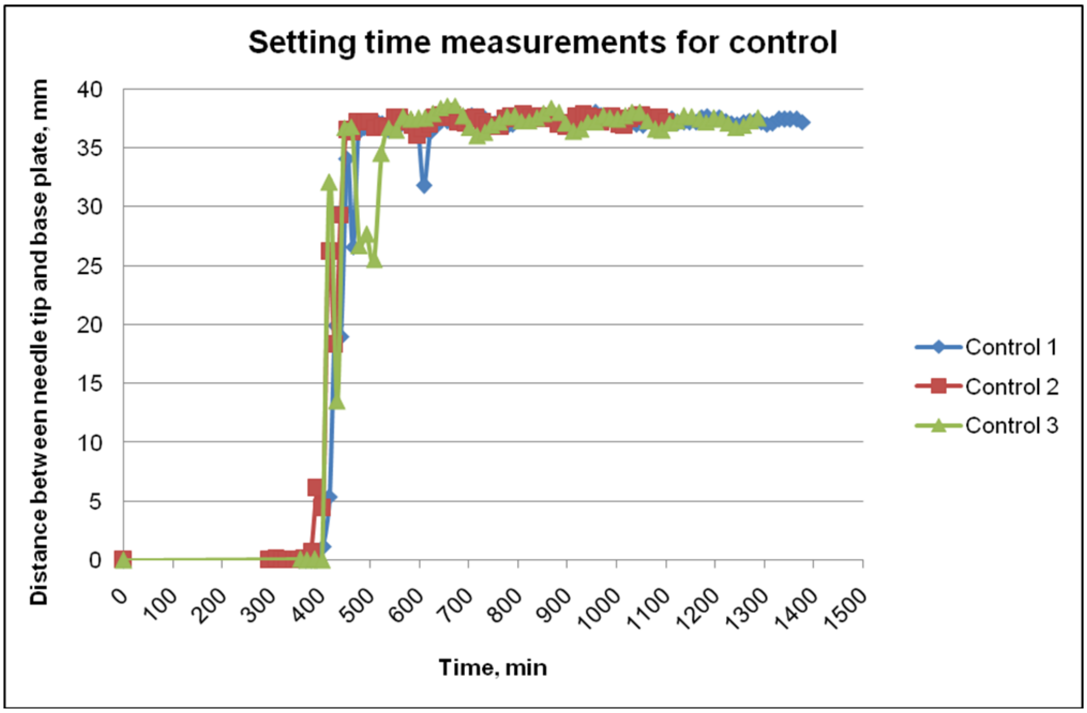

Figure 3: Setting time graph for the Control sample

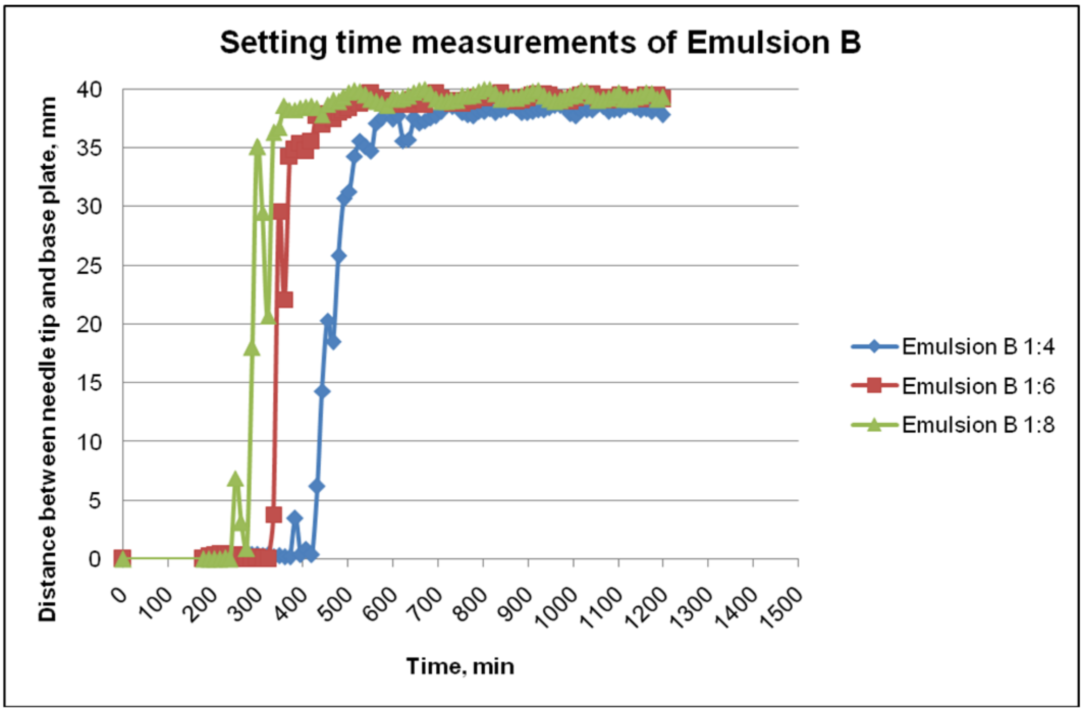

Figure 4: Typical setting time graph for Emulsion B at different dosages.

The setting time of a mortar is affected by a number of items which includes: water-cement ratio, cement-sand ratio, polymer-water ratio, temperature and humidity. Knowing the setting time of mortars are important as the initial set should not be too early and the final set should not be too late. The two setting times are defined as: Initial set – occurs when the mortar starts to stiffen and cannot be properly handled and placed and Final set – occurs when the mortar begins to harden and can sustain a load [10].

A summary of the observations made for the various emulsion at the different dosages is presented in Table 1. The setting time of each specimen is calculated as T_f -T_o. Based on these values. the following observations were made:

- The control samples have the shortest setting time (average of 94 minutes)
- The setting time of Emulsion C 1:8 is the same as the control sample
- Emulsion B 1:4 has the longest setting time of all the mortar samples (312 minutes)
- Emulsion A 1:8 and Emulsion B 1:6 had the most rapid initial set at 178.3 minutes
- Emulsion C 1:4 had the slowest initial set at 550 minutes
- Emulsion B 1:8 was most rapid final set specimen at 334 minutes
- Emulsion C 1:4 was the slowest final set specimen at 790 minutes

The polymer dosage ratio had a significant effect on the setting time of the mortar samples. As the polymer-water ratio increases from 1:8 to 1:4, the setting time of mortar with each of the emulsions A, B and C increased. This is ascribed to the higher amount of moisture a 1:4 dosage sample has compared to the lower dosage 1:8 sample. The different polymer emulsions also had an effect on the setting time of the mortar especially at the lower dosage with emulsion A.

Table 1: Setting times and observations of specimens

Sample	Initial Set (T_o) [min]	Final Set (T_f) [min]	Setting time, [min]	Implication	Shape of graph	Implication
Control 1	393.58	489.58	96	Fast set	Relative spiky	Some voids, non-uniform hydration
Control 2	356.49	452.49	96	Fast set	Relative spiky	Some voids, non-uniform hydration
Control 3	358.07	448.07	90	Fast set	Relative spiky	Some voids, non-uniform hydration
Emulsion A 1:4	299.13	539.13	240	Slow set	Relative spiky	Some voids, non-uniform hydration
Emulsion A 1:6	328.43	520.43	192	Moderate set	Relative smooth	No voids, uniform hydration
Emulsion A 1:8	178.29	358.29	180	Moderate set	Relative smooth	No voids, uniform hydration
Emulsion B 1:4	214.59	526.59	312	Slow set	Relative spiky	Some voids, non-uniform hydration
Emulsion B 1:6	178.35	394.35	216	Slow set	Relative spiky	Some voids, non-uniform hydration
Emulsion B 1:8	214.24	334.24	120	Fast to Moderate set	Relative spiky	Some voids, non-uniform hydration
Emulsion C 1:4	550.04	790.04	240	Slow set	Relative spiky	Some voids, non-uniform hydration
Emulsion C 1:6	357.58	477.58	120	Fast to Moderate set	Relative spiky	Some voids, non-uniform hydration
Emulsion C 1:8	298.30	394.30	96	Fast set	Relative smooth	No voids, uniform hydration

Compressive Strength Tests

Three specimens of each sample set were tested for a statistical analysis. A test result was considered valid if the difference between the highest and lowest did not exceed 15% of the average. Typical results of both the control and the polymer emulsions type A modified specimens at a dosage rate of 1:4 are presented in Fig. 5 and Fig. 6.

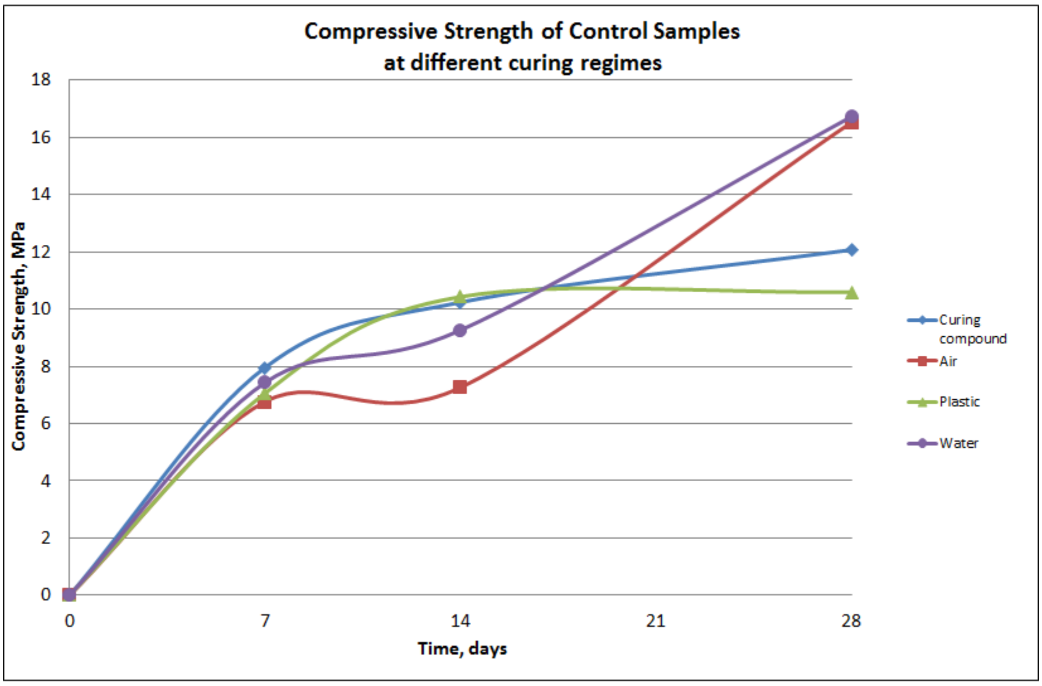

Figure 5: Compressive strength of control specimens at different curing regimes

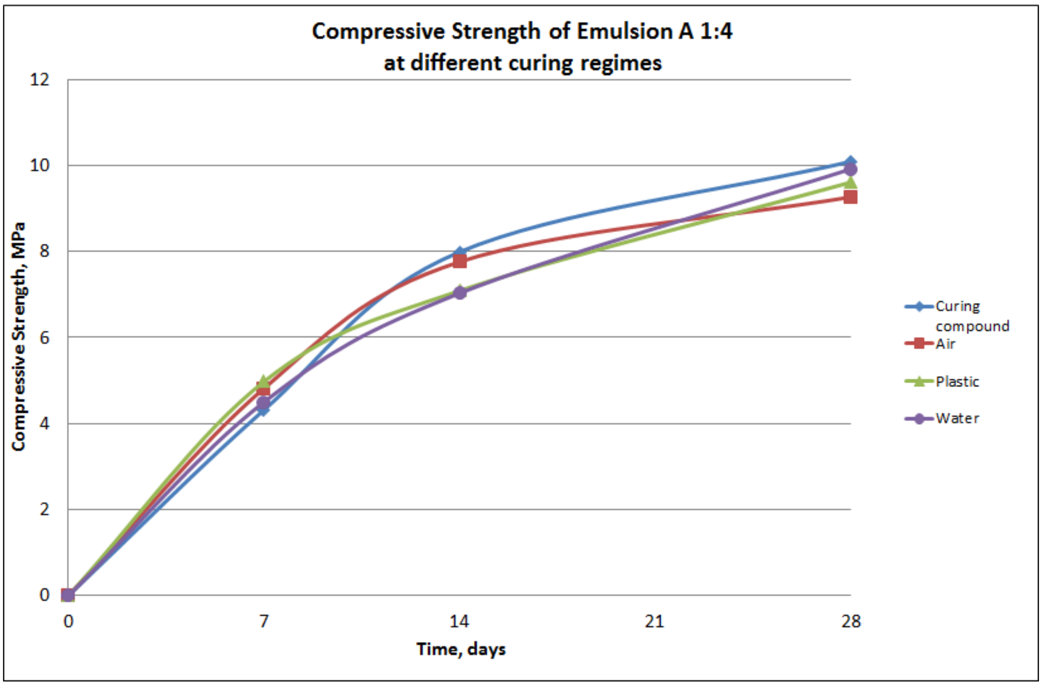

Figure 6: Compressive strength of Emulsion A 1:4 at different curing regimes

The following observations were made:

- As expected, the water curing regime of the control specimen resulted in the highest compressive strength of all the cubes tested at 16.7MPa.
- The compressive strengths of cubes made with mortar using Emulsion A are not much influenced by varying curing regimes but the stengths obtained using a 1:4 dosage of this emulsion is markable lower than dosages of 1:6 and 1:8. This indicated that Emulsion A reduces the need for rigorous curing but higher dosages of Emulsion A reduces the compressive strength of repair mortars.

- Dosage rates of all Emulsions have a marked influence on the compressive strength of mortars. The higher the dosage rate, the lower the compressive strength of the mortar cubes.
- Each of the various Emulsions tested had a noticeable effect on the compressive strength of the mortar cubes in comparison to the compressive strength of unmodified mortars. Typically the compressive strength is reduced by 25% from 17MPa to 13MPa under water curing conditions.
- When using the various Emulsions as modifiers, the different curing regimes did not have a major impact on the compressive strengths of the mortars. This could be explained by the forming of a polymer film in the modified mortars protecting it from moisture loss. This reduces the need for extended water curing [11].

Crack Formation Tests

Crack formation data for the control specimens are given in Table 2. Cracks formed under all but the curing compound regime. No cracks was noticeable in any specimens made from mortar modified by any of the dosage rates of emulsions A, B and C and exposed to any of the different curing regimes.

Table 2: Crack formation results for air curing of the control (unmodified) specimens

Test Age	Crack No.	Length, mm	Width, mm	Crack area, mm^2	Total Area mm^2
1 day	1	50.500	0.180	9.090	
	2	23.000	0.210	4.830	
	3	21.500	0.200	4.300	**18.220**
7 day	1	50.500	0.180	9.090	
	2	23.000	0.210	4.830	
	3	21.500	0.200	4.300	
	4	70.000	0.100	7.000	**25.220**
28 day	1	50.500	0.180	9.090	
	2	23.000	0.210	4.830	
	3	21.500	0.200	4.300	
	4	70.000	0.100	7.000	
	5	68.000	0.080	5.440	**30.660**

Conclusions

Polymer emulsions have an effect on the setting time, compressive strength and crack formation of cementitious patch repair mortar.

The setting time of a mortar specimen is certainly affected by polymer emulsions and different dosages of such polymer emulsions. In general, a polymer emulsion increases the setting time of a cementitious mortar. The different polymer emulsions tested had different influences but it was found in all the tests that the higher the polymer dosage, the longer the time span from initial to final set of the mortar.

When polymer emulsions are added to a cementitious mortar, it decreases the compressive strength. The higher the polymer dosage, the lower the compressive strength of such modified mortar.

When polymer emulsions are added to a cementitious mortar, a polymer film is formed that bridges micro cracks during the hydration period and as such, prevents crack propagation and moisture loss. It was clear that with modification of repair mortars with a polymer emulsion, no crack formation takes place because of the polymer film formation which forms strong bonds between the cement hydrates and the sand particles. This hold true under constant ambient conditions and needs to be confirmed under varying ambient conditions.

In short, the addition of polymer emulsions to a repair mortar will improve the cracking resistance but does not improve the strength or the setting time of such a cementitious mortar.

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